Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 78 (2015) 1275 – 1280
Energy Procedia

6th International Building Physics Conference, IBPC 2015

Influence of Hygroscopic Materials in the Stabilization of Relative Humidity Inside Museum Display Cases

C. Ferreira[a], V. P. de Freitas[a], N. M. M. Ramos[a] *

[a] CONSTRUCT-LFC, Faculty of Engineering (FEUP), University of Porto, Rua Dr. Roberto Frias, 4200-435 Porto, Portugal

Abstract

The preservation of artworks is profoundly influenced by fluctuations in temperature and, especially, relative humidity. Thus, it is crucial for hygrothermal conditions in museums to be stabilized, particularly inside display cases.
Today there are advanced hygrothermal simulation models available that enable us to quantify the temperature and relative humidity fluctuations of the air inside the museum display cases, provided that we know the climate in the exhibition rooms, the degree of ventilation of the display case and the constitution of its surroundings. However, the placement of hygroscopic materials inside display cases also influences the fluctuation of interior relative humidity.
This paper presents the results of an experimental study conducted in a flow chamber, showing the enormous potential of hygroscopic materials in stabilizing relative humidity inside of display cases. In addition, it presents a numerical simulation study conducted in display cases evaluating how the insertion of hygroscopic finishing materials in the base of the display case, under varying ventilation conditions influences stabilization of interior relative humidity.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Hygroscopic Materials; Relative Humidity; Museums; Display Cases;

1. Introduction

When remodelling museums housed in older buildings, the use of active systems to control of indoor climate conditions has been favoured over the use of passive systems. However, in temperate/Mediterranean climates such

* Corresponding author. Tel.: +351 220 413 714; fax: +351 225 081 940.
E-mail address: cmiranda@fe.up.pt

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.291

as Portugal, display cases can be used in these types of buildings to contribute decisively to ensuring natural control over the fluctuation of relative humidity without the use of complex active systems. Inside the case, relative humidity fluctuation is controlled through the use of interior hygroscopic inertia, coupled with adequate ventilation. Hygroscopic inertia represents the ability of finishing materials to store air and moisture from the air and return it to the space when relative humidity is low.

2. Hygrothermal Conditions in Display Cases

Display cases have long been used in conservation to display, protect and minimize damage and deterioration of museum objects. Display cases protect against vandalism, theft and other risks from visitors. In terms of conservation, display cases protect their contents against environmental effects, in particular variations in the microclimate, chemical pollution and the action of microorganisms [1]. Display cases can be understood as a passive system to control indoor relative humidity if they are not equipped with any active means to control the indoor climate, such as the relative humidity control module for display cases developed by Michalski, or a mechanical ventilation system [2,3].

Display cases can be completely sealed or ventilated. According to Tim Padfield, sealed display cases are not only difficult to work with but may have a detrimental effect on the works of art they contain. Sealed cases may act as greenhouses, allowing the emission of organic volatile compounds (VOC) or favouring microbial colonization or the proliferation of insects. Ventilated cases should have a small circular hole approximately 5 cm in diameter per cubic meter of air to allow for air movement. Air entering the display case must pass through a filter that removes dust and pollutants, and cases should contain abundant absorbent material to stabilize the environment against variations in relative humidity. Tim Padfield further warns against the heating effect caused by illumination, which should not be overlooked [4].

Relative humidity inside display cases varies depending on the rate of air exchange between the inside and outside, which may occur through one of the following processes: diffusion through the porous structure of the materials used in case construction; air flow caused by variations in temperature and pressure; or convective air flow [5]. According to Thomson, there are two passive (non-mechanical) methods to reduce variations in relative humidity inside display cases: use of materials that can buffer relative humidity changes and the use of certain salts or saturated solutions [6].

Some studies show a benefit from the use of materials with buffering capabilities – such as wood, cotton and paper – inside display cases. However, designers must always be aware of the air exchange rate of the case, the type and amount of hygroscopic material, and the composition of the museum objects to be housed [7].

The use of silica gel was first suggested by Toishi and later adopted by Stolow as a good stabilizer material. Silica gel should not be used in its dry form but rather in equilibrium with the demand for relative humidity of the air [8]. The use of a saturated solution of sodium bromide covered with a silicone rubber membrane has been evaluated, with the researcher concluding that this method is less effective than others already studied, and furthermore that it needs to be used in combination with the large amount of absorbent material [5]. In 2009, a partnership among three Russian institutions resulted in the development of a new absorbent material – ARTIC-1 – for use in display cases. Its development was based on the solid-gas chemical reaction between an inorganic salt and water vapour. This new material was first tested in a prototype display case, where its reliability and effectiveness in stabilizing relative humidity variations was confirmed; the study showed that the ARTIC 1 material may offer better properties than aqueous solutions available on the market. The material was then tested in display cases in actual museums, where its strong performance has been confirmed [9].

March 2014 saw the publication of EN 15999-1:2014 - Conservation of cultural heritage - Guidelines for design of showcases for exhibition and preservation of objects - Part 1: General requirements. This is the first of two standards that provide requirements for display cases. This standard specifies the general characteristics and conditions for use of display cases to safely display museum objects, in order to reduce environmental interaction and to satisfy preservation requirements [10]. The second part of the standard, ENEN 15999-2: 2014 - Conservation of cultural heritage - Guidelines for design of showcases for exhibition and preservation of objects - Part 2: Technical aspects, is focused on more technical aspects related to display case requirements. Part 2 of the standard is currently under development, with no date yet set for publication.

This article is the result of our belief in the importance of studies aimed at quantifying the passive effect of hygroscopic materials in stabilizing relative humidity.

3. Assessing the Influence of Hygroscopic Materials

To assess the influence of hygroscopic materials in display cases, we used a test apparatus that belongs to the Building Physics Laboratory. This test apparatus consists of a flow chamber equipped with a monitoring system, installed inside a climatic chamber whose climate can be controlled by the user. The prototype flow chamber resembles a display case and was developed at the LFC-FEUP as part of Ramos's doctoral dissertation [11]. The flow chamber consists of a plexiglass box 1500 mm long, 524 mm wide and 584 mm high, with three openings providing access to its interior, through which hygroscopic material is introduced. This chamber is also equipped with a ventilation system and a vapour generating system, which was not used in this study.

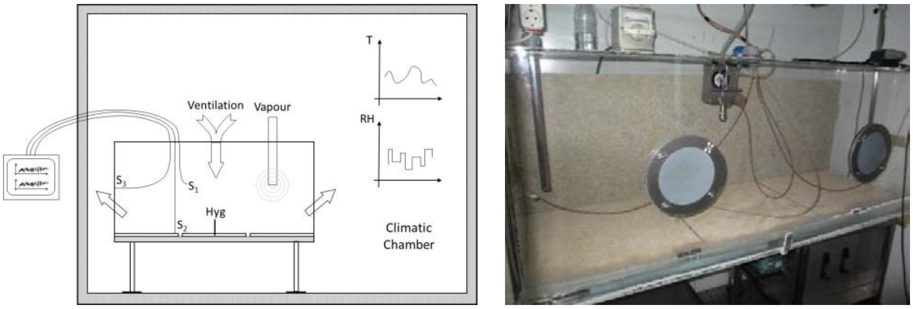

Fig. 1. (a) Schematic representation of the test apparatus [11]; (B) LFC flow chamber showing the opening for introducing hygroscopic material.

This apparatus allowed us to conduct a set of tests aimed at assessing the influence of hygroscopic materials and ventilation in relative humidity fluctuation inside the flow chamber. The flow chamber was subjected to an exterior climate generated by the surrounding climate chamber. Inside the flow chamber we placed different hygroscopic finishing materials, and we assessed two different hourly air exchange rates.

The climate outside the flow chamber was set based on average indoor climate conditions in Portuguese museums. The test lasted for 24 days, during which time the temperature ranged from 15 to 24 °C and relative humidity between 50 and 70%. We assessed the following ventilation scenarios: without ventilation (R_{ph} = 0 h^{-1}) and with ventilation (R_{ph} = 0,3 h^{-1}). The tests assessed the following finishing materials: spruce wood wool board coated with mineral binders (A) and wood fibreboard bonded with white cement (B). These materials were placed in the flow chamber finishing the bottom horizontal surface (0.75 m^2), also finishing the back vertical surface (0.75 m^2) when the two materials were inserted in the same trial. Table 1 shows the characteristics of the trials conducted in the flow chamber.

Table 1. Characteristics of trials conducted in flow chamber.

Trial	CC	Flow chamber	
	Cycle	R_{ph} (h^{-1})	Hygroscopic Materials
IHV1	24 days	0.00	-
IHV2	24 days	0.30	-
IHV3	24 days	0.00	0.75 m^2 material A
IHV4	24 days	0.30	0.75 m^2 material A
IHV5	24 days	0.00	0.75 m^2 material B
IHV6	24 days	0.30	0.75 m^2 material B
IHV7	24 days	0.00	0.75 m^2 material A and 0.75 m^2 material B
IHV8	24 days	0.30	0.75 m^2 material A and 0.75 m^2 material B

Fig. 2(a) shows the variation in relative humidity in trials IHV1, IHV3, IHV5 and IHV7, in all of which the flow chamber was without ventilation and where the finishing material and respective area was varied. Fig. 2(b) shows the variation in relative humidity in trials IHV2, IHV4, IHV6 and IHV8, in all of which the flow chamber had an hourly air exchange rate of $0.3h^{-1}$, with various configurations of the finishings. Both figures also show the average variation in temperature and relative humidity recorded inside the climatic chamber (CC).

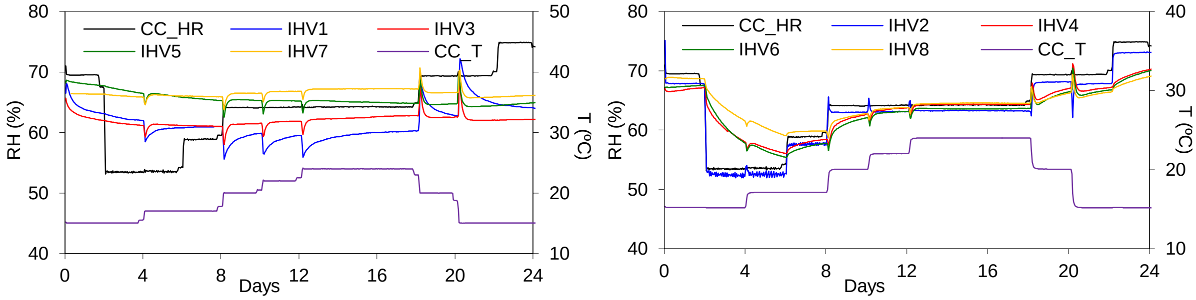

Fig. 2. (a) Mean variation in temperature and relative humidity inside the climatic chamber (CC) and mean variation in relative humidity inside the flow chamber in trials IHV1, IHV3, IHV5 and IHV7; (b) Mean variation in relative humidity in the climatic chamber and temperature and relative humidity inside the flow chamber in trials IHV2, IHV4, IHV6 and IHV8.

The results of the trials with respect to variation in relative humidity inside the flow chamber due to the imposed demand show that if there is no ventilation, the insertion of hygroscopic materials inside the chamber significantly improves stabilization of relative humidity. However, when the flow chamber is ventilated, the influence of the interior hygroscopic finishing materials is less apparent, because it was found that at each demand the interior relative humidity tended to approximate the relative humidity outside the flow chamber. These tests allow us to conclude that the introduction of hygroscopic materials inside the flow chamber helped stabilize interior relative humidity, but that the tested air exchange rate $R_{ph} = 0.3\ h^{-1}$ practically eliminates the effect of the hygroscopic finishing material.

4. Numerical Study

The numerical study was conducted using previously validated Wufi Plus hygrothermal model of advanced numerical simulation [12]. This study aimed to evaluate the performance of display cases with various surface areas of different hygroscopic finishing materials and ventilation rates. The display case to be assessed is cubic in shape, measuring 1 x 1 x 1 m^3, and all of its faces are transparent except for the bottom horizontal surface, which may consist of glass or which may be lined with a hygroscopic material in differing areas (Fig. 3(a)).

The climate outside the display case reflects the indoor climate of the exhibition gallery where the display case is located, in which the temperature and relative humidity values are those defined in Fig. 3(b).

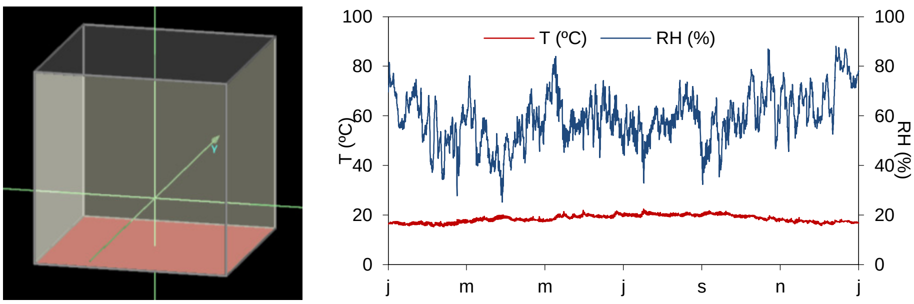

Fig. 3. (a) Geometry of the display case used in the numerical study; (b) Variation in temperature and relative humidity in the environment outside the case.

The hygroscopic material used was spruce wood wool board coated with mineral binders (material A) placed on the bottom surface of the case. The amounts of material considered were: 0 m^2 (empty case), 0.10 m^2, 0.25 m^2 and 1 m^2 (surface fully lined with hygroscopic material). Hygroscopic capacity was calculated for the different configurations ($Cap_{hygroscopic}$) for the display case using equation (1), yielding 0 g/m^3.%RH for the empty display case, 0.22 g/m^4.%RH for the display case with 0.10 m^2 of hygroscopic material, 0.55 g/m^3.%RH for the display case with 0.25 m^2 of hygroscopic material and 2.2 g/m^3.%RH for the display case with 1 m^2 of hygroscopic material. That is, when the relative humidity ranges from 33 to 75% the hygroscopic capacity of the chamber is 0 g/m^2, 9.24 g/m^2, 23.1 g/m^2 and 92.4 g/m^2, respectively.

$$Cap_{hygroscopic} = \frac{\sum_i MBV_i \cdot S_i}{V} \, g/m^3.\%HR \qquad (1)$$

Five ventilation flows were considered: without ventilation (R_{ph} = 0.0 h^{-1}), which replicates a completely airtight display case; a case with very limited ventilation (R_{ph} = 0.05 h^{-1}); a case with limited ventilation (R_{ph} = 0.1 h^{-1}); a case with moderate ventilation (R_{ph} = 0.2 h^{-1}); and a case with slightly elevated ventilation (R_{ph} = 0.3 h^{-1}).

Fig. 4 shows the variations in temperature and relative humidity obtained for two of the twenty simulations performed. Simulation 5 corresponds to the empty display case, with an hourly air exchange rate of 0.3 h^{-1}, and simulation 16 reflects a display case with 1 m^2 of hygroscopic material and no ventilation.

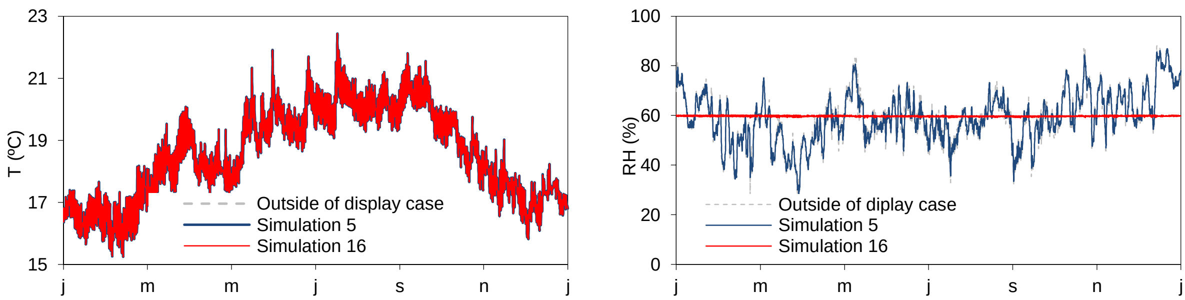

Fig. 4. (a) Variation in temperature for simulations 5 and 16; (b) Variation in relative humidity for simulations 5 and 16.

Minimum, median and maximum relative humidities were calculated for each simulation performed, as well as the parameter Relative Humidity Stabilization (RHS), which allows us to quantify the performance of the various solutions in stabilizing relative humidity; this variable is the result of the sum of absolute differences in hourly relative humidity and the 90-day seasonal average for relative humidity [13]. Fig. 5 shows variation of the parameter *RHS/h* according to the hygroscopicity capacity and hourly air exchange rate.

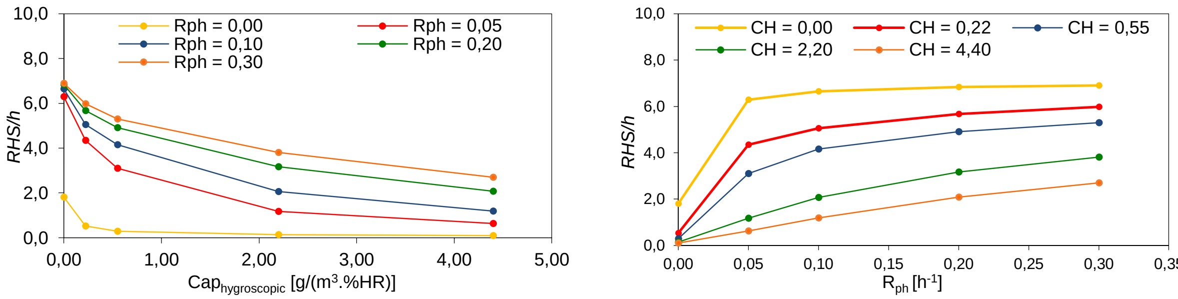

Fig. 5 (a) Variation of the parameter *RHS/h* according to the hygroscopic capacity; (b) Variation of the parameter *RHS/h* according to the hourly air exchange rate.

By analyzing the above figures we can conclude that the increase in hygroscopicity within the display case decreases the parameter *RHS/h*: that is, it decreases fluctuation in interior relative humidity. The stabilizing effect of hygroscopic materials is more noticeable in display cases with lower hourly air exchange rates. We can also conclude that variation in relative humidity – that is, the parameter *RHS/h* – increases with increasing air exchange rates (R_{ph}). We should stress that beginning at air exchange rates on the order of 0.05 h^{-1}, the hygroscopic effect clearly decreases.

5. Conclusions

The main conclusions of this study are as follows: display cases can be used as a passive technique for controlling relative humidity inside museums; the experimental study conducted in the laboratory flow chamber confirms the potential of hygroscopic materials for controlling indoor relative humidity; based on the Wufi Plus advanced model of hygrothermal simulation we are able to evaluate the influence of various surface areas of hygroscopic materials inserted in a display case on fluctuation of interior relative humidity, as well as the hourly air exchange rate.

Acknowledgments

Cláudia Ferreira would like to thank Fundação para a Ciência e Tecnologia (FCT), Ministério da Ciência, Tecnologia e Ensino Superior, Portugal, for their financial support through grant SFRH/BD/68275/2010.

References

[1] Dario Camuffo et al. – Showcases: a really effective mean for protecting artworks. Thermochimica Acta, Volume 365, Issues 1–2, 29 December 2000, P 65–77. http://www.sciencedirect.com/science/article/pii/S0040603100006146

[2] Michalski, S. – A control module for relative humidity in display cases. Studies in Conservation, Volume 27, Issue Supplement-1 (01 January 1982), pp. 28-31.

[3] Lony, R. J. M. et al. – Evaluation of the climate control performance and reability of active display cases. N.T. Bayazit, G. Manioğlu, G.K. Oral, Z. Yilmaz (Eds.), Proceedings of 4th International Building Physics Conference, Istanbul, May 15th–18th (2009), pp. 679–686

[4] Padfield, Tim – The design of museum showcases. Preprints of the London Conference of the International Institute for Conservation 1967, edited by G.Thomson. pp 119-126.

[5] Thomson, Garry – The museum environment. Second edition. Oxford: Elsevier Butterworth-Heinemann 1986. ISBN 0-7506-2041-2.

[6] Padfield, Tim – The control of relative humidity and air pollution in showcases and picture frames. Studies in Conservation, 11 (1966). pp. 8-30. http://www.conservationphysics.org/showcase/showcase.pdf

[7] Thomson, Garry – Relative Humidity variation with temperature in a case containing wood. Studies in Conservation, Volume 9, Issue 4 (November 1964). pp. 153-169. http://www.maneyonline.com/doi/abs/10.1179/sic.1964.025

[8] Toishi, Kenzo – Humidity Control in a Closed Package. Studies in Conservation. Volume 4, Issue 3 (August 1959), pp. 81-87. http://www.maneyonline.com/doi/abs/10.1179/sic.1959.018

[9] Glaznev, Ivan et al. – ARTIC-1: A New Humidity Buffer for Showcases. Studies in Conservation, Volume 54, Issue 3 (01 January 2009), pp. 1-16. http://www.maneyonline.com/doi/abs/10.1179/sic.2009.54.3.1

[10] CEN – EN 15999-1: Conservation of cultural heritage - Guidelines for design of showcases for exhibition and preservation of objects - Part 1: General requirements. 2014.

[11] Ramos, Nuno – A importância da inércia higroscópica no comportamento higrotérmico dos edifícios. Tese de Doutoramento em Engenharia Civil. Faculdade de Engenharia da Universidade do Porto, Porto, 2007.

[12] Ferreira, C.; Peixoto de Freitas, V. e Ramos, Nuno M. M. – Quantificação da Influência de Materiais Higroscópicos na Flutuação da Humidade Relativa em Museus Instalados em Edifícios Antigos. 5º Encontro Sobre Patologia e Reabilitação de Edifícios – PATORREB2015. Porto, 26 a 28 de Março de 2015.

[13] Martens, M. H. J. – Climate Risk Assessment in Museums: Degradation risks determined from temperature and relative humidity data. Tese de Doutoramento. Eindhoven University of Technology, Eindhoven, 2012.